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Color vision tests using a calibrated color monitor controlled by a microprocessor

David Wolf

COLOR VISION TESTS USING A CALIBRATED COLOR MONITOR CONTROLLED BY A MICROPROCESSOR

by

David A. Wolf

A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in the School of Imaging and Photographic Sciences in the College of Graphic Arts and Photography of the Rochester Institute of Technology

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Date

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ABSTRACT

A feasibility study was performed to determine if colors on a CRT could be measured accurately and then controlled by a computer to provide a means of performing color vision tests. Benefits from using a calibrated computer/monitor system could be decreased testing time, exact diagnosis, and possibly the means of quantifing the degree of the deficiency. The Atari 800XL Computer with a Sakata color monitor were used for the experimentation due to their low cost, availability, and ability to create the largest number of colors of any computer in the same price range. The system was calibrated and color vision tests were performed with five subjects of known deficiencies. The results were compared to testing with the Ishihara Charts. The color vision tests with this system were able to detect for major color deficiencies without any difficulty. The color vision test was able to distinguish between trichromatic and dichromatic vision and the types of dichromats.

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The support of the Vixia Computer Center for providing the necessary computer system is also acknowledged with appreciation.

DEDICATION

This thesis is dedicated to my mother and father who's continual guidance and love will always be the foundation of my success in life.

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I. INTRODUCTION.

A. Overview of Research Project.

Color vision tests provide the important function of characterizing an individual's capability of distinguishing various colors. The proliferation of color into most consumer goods and manufacturing processes has developed the need to evaluate an employee's vision accurately. Color coded wire, resistors or other electronic parts are common examples of situations where color discrimination will directly relate to an employee's ability to complete a task properly. Various color vision tests are available, for example, Ishihara Chart Test or the American Optical Society charts. However, these just provide a 'pass/fail' approach to diagnosing a subject as color blind. Dimmick asserts that the pseudo-isochromatic charts "...do not measure in any sense, a subject's color vision. They simply 'catch' certain individuals who are unable to read them."[1] Situations occur where a subject is considered color blind, yet their exact deficiency may not disqualify them from a particular job since the severity of the deficiency was not measured.

It is the author's intent to utilize the available research on the subject of color deficiencies to develop and test the feasibility of a color vision test using a calibrated color monitor controlled by a computer. Such a

test could allow the colors being examined to be adjusted during the testing. If the colors are controlled, the administrator of the test can examine more closely the subject's deficiency by entering various color combinations based on the known confusion colors for a particular deficiency. Simple analysis of the results could provide a more precise diagnosis than 'pass/fail' type tests. The majority of the color screening tests do not have the ability to quantify the results. If a color vision test was developed based on quantitative investigation according to accepted color specifications (such as the CIE chromaticity diagram), the results from such a test would not only indicate a defect but how much of a defect is present. The recent development of computers, color monitors, and spectroradiometers provide the necessary ingredients for such a test.

The current technology of computers with high resolution graphics and color capabilities allow for the physical equipment requirements of creating and controlling a magnitude of colors. Computer systems are available that can create upwards of 16 million shades of colors, such as a system by Advanced Electronic Design costing approximately $40,000.[2] Although such equipment does exist, the exorbitant cost prohibited its use in this project. A more affordable system, such as the Atari 800XL home computer, is available for under $500, and can create 256 different colors. Even though the Atari 800XL cannot create as many colors as the Advanced Electronic Design system, it is has

the largest amount of colors then any system below the $1,000 dollar range. Using the Atari system will provide enough colors to test the feasibility of working with a color monitor for color vision tests.

Modern spectroradiometers have become so extremely sophisticated that instant spectral scanning systems are common along with CRT graphics output and computer interfaces. The systems can also provide instant computation of such parameters as tristimulus values and chromaticity coordinates. The use of spectroradiometers to measure the color of CRTs has been investigated by Donofrio and Ryan[3] and described as a viable method for checking the accuracy of the CRT.

By combining the use of a spectroradiometer and the Atari 800XL computer, the feasibility of performing color vision tests with a calibrated monitor can be investigated. The results of such an investigation can provide a foundation as to whether or not a more elaborate system would be worth evaluation.

B. Background on Chromatic Vision.

The normal observer is considered to be a subject who can distinguish all of the colors of the visible spectrum, with the highest sensitivity being between 540 and 570nm or an average of 555nm. The luminosity function in Figure #1

illustrates this fact.[4]

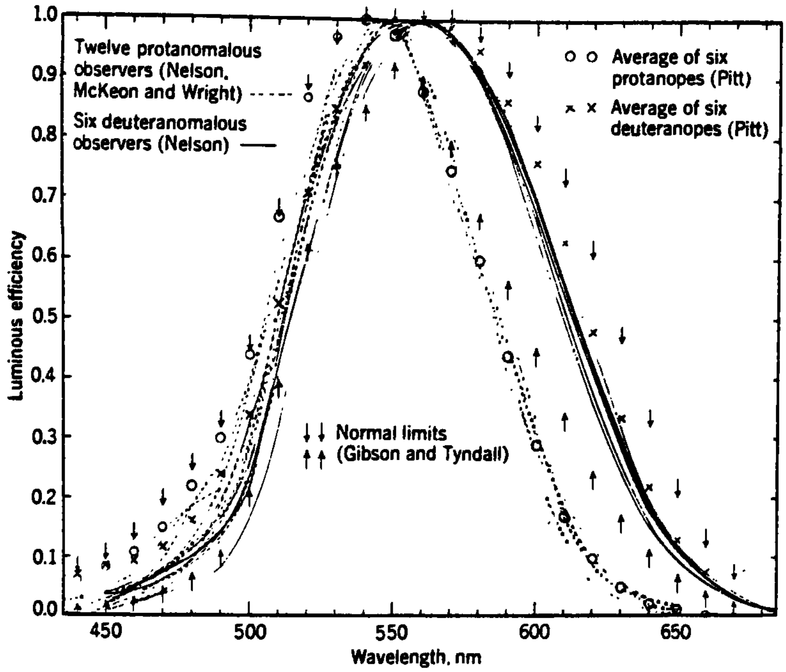


Figure 1: Luminosity function of normal and color-defective observers[4]

The Young-Helmholtz theory of color vision uses the concept that the three primary colors, red, green, and blue, when mixed can create all of the colors visible to the normal observer.[5] "There are three types of cones, each containing a different pigment...the three pigments have different absorption spectra so that the responses of the three types of cones depend differently on the spectral power distribution of the light reaching them."[6] Figure #2 represents relative sensitivity of the three types of cones in the human retina.[7] The cone responses of the retina are analogous to mixing colors using three primaries; red, green, and blue. The analogy of these primaries

representing the spectral response of the retina will be used throughout the paper.

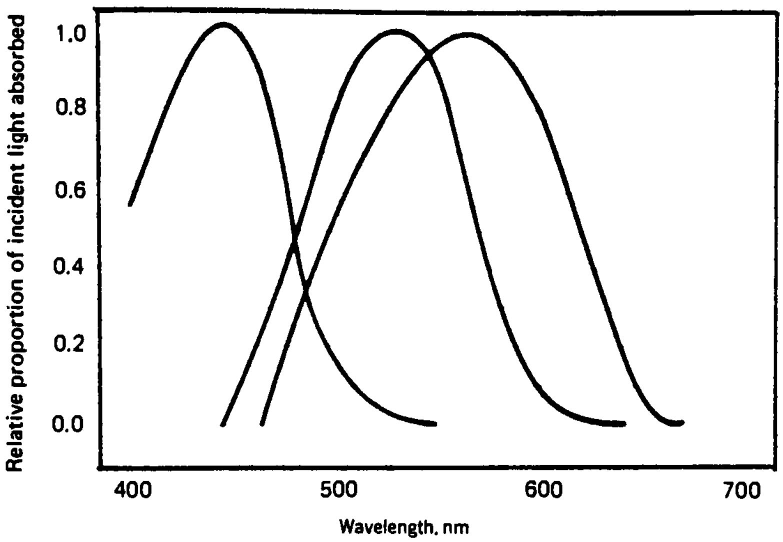


Figure 2: Relative sensitivity of the three types of cones in the human retina.[7]

The name for the normal observer is trichromat, based on Young's theory of the three primaries representing this visual response. The discriminations possible by a trichromat are light-dark, yellow-blue, and red-green. Abnormal color vision is distinguished by various combinations of these discriminations. The primaries in different combinations will illustrate the visual response of the various color deficiencies.

There are two general causes of color deficiencies: congenital and acquired. "Color blindness occurs when genetic factors or disease have eliminated one or more types of cones."[8] Congenital color blindness means inherited. The woman will transmit to her son or daughter the necessary genes. If the man is color blind then the son will also be color blind whereas the daughter will be a carrier and

infrequently is also color blind.

Acquired color blindness can be attributed to disease or accident. Diseases effecting the retina, optic nerve such as multiple sclerosis, can cause the defect. Color field defects are also connected to toxic amblyopia which depresses the central field. Examples of such toxins are found in lead poisoning, carbon disulfide (used in the preparation of rubber, explosives, insecticides among others), spinal anesthesia, thallium (rat poisson), tabacco, and alcohol which are most common.[9]

C. Early Development of Color Deficiencies.

The discovery of color deficiencies is a relatively recent phenomenon of the late eighteenth century. Early descriptions of color defectives were made by Huddart (1777), Scott (1778) and Dalton (1794).[10] John Dalton's case was the first complete analysis of color deficiency, since it was Dalton himself who was the subject of his study. Dalton could only see yellow and blue. His spectrum was made up of various shades of yellow at the long end, and a neutral area in the middle leading to the short end of the spectrum with various shades of blue. He believed that the defect was caused by the absorption of red by the eye media.

It was Thomas Young who inferred that the fibers in the retina were not able to perceive red. According to him, the

fibers were either missing or damaged. Hershel, using Dalton as his subject, determined that abnormals did in fact perceive every wavelength of light a normal trichromat observed. Dalton disagreed with Hershel's conclusions and was not proved wrong until he died. Dalton's eye media was tested and determined to transmit red.

The importance of color vision tests was realized after a major railroad accident is Sweden in 1875. The accident was due to a trainman who was not able to distinguish between red and green signals. The need for classifing observers' color vision by testing became a major concern of researchers.

D. Color Vision Disorders.

The major catagories of color disorders are anomalous trichomatism, dichromatism, and monochromatism. An anomalous trichromat matches colors by mixing the three primaries similarly to the normal trichromat. The difference, however, is that anomalous trichromats use different amounts of the primaries to create the same colors. This effect is due to the actual cone responses being weaker according to the type of deficiency. The chromatic distinctions are weaker for anomalous trichromats and have two sub-categories: protanomaly and deuteranomaly. Protanomous is deficient in the long-wave end and has a shifted bright spot to 540nm (see figure #1). The bright

spot corresponds to the wavelengths which are most visible to the observer. Deuteranomous has no loss at the long end and has a shift to the right on the luminosity function to 560nm.

Dichromatism has visual response equal to two primaries, with discrimination being light-dark and either yellow-blue or red-green. The trichromatic theory of the CIE standard observer has been adapted to explain and approximate dichromatism.[11] In order to approximate the color matching properties of normal trichromats, color-matching functions of dichromats have been determined based on the theory that dichromatism is a reduced form of trichromatism (see table #1).

In 1855, Maxwell, using his color triangle, made it possible to define confusion colors. He said, "If we find two combinations of colours which appear identical to a colour-blind person, and mark their positions on the triangle of colour, then the straight line passing through these points will pass through all points corresponding to other colours, which, to such a person, appear identical with the first two."[12]

Experimentally, the primary stimuli representing the same chromaticity for the three types of dichromats can be represented on the trichromatic chromaticity diagram. These lines created by the same primary stimuli will converge on one point uniquely defined for each deficiency. This point is called the confusion point (See figure #3).[13]

The coordinates accepted for this research project are:

(P) x= 0.747, y= 0.253

(D) x= 1.080, y= -0.080

(T) x= 0.171, y= 0.000

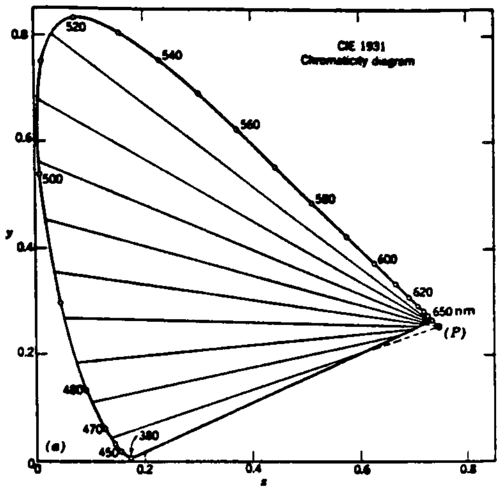
taken from Wyszecki and Stiles based on Pitt's findings.[14]

"The chromaticity for a dichromatic observer is therefore wholly determined by the ratio of the two remaining responses. For this ratio constant, there is defined on the normal chromaticity diagram, a straight line passing through the point representing the missing primary."[15] This straight line has been termed a confusion line. The confusion colors for dichromats are indicated in figure #3 along the various lines. The separation of the confusion lines indicate colors that have just noticable differences to the indicated observer. This prediction of confusion lines comes from the theory by Young-Helmholtz and was verified by Pitt in 1935.[16]

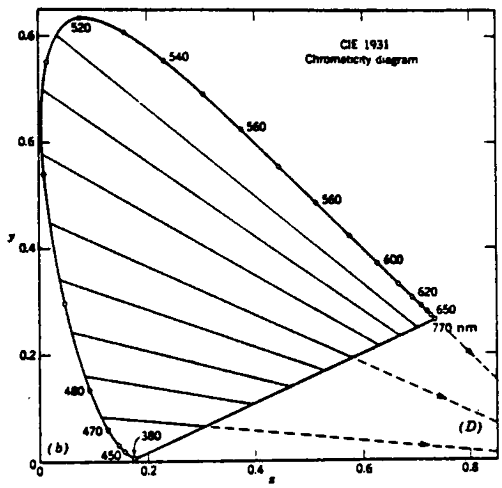
There are four sub-categories of dichromatism: protanopes, deuteranopes. tritanopes, tetartanopes. Protanopes are called red blind since they experience a shortening of the long wave. "Cone vision involves different retinene-protein combinations called iodopsin, which absorb at longer wavelengths than rhodopsin [found in the rods]."[17] It is the lack of iodopsin or problems with the physical mechanism which causes protanopic vision. The bright point for a protanope is 540nm, as shown in figure #1. Protanopes respond only to yellow and blue wavelengths

Wavelength λ(nm)	Protanope $\bar{p}_1(\lambda)$	Protanope $\bar{p}_2(\lambda)$	Deuteranope $\bar{d}_1(\lambda)$	Deuteranope $\bar{d}_2(\lambda)$	Tritanope $\bar{t}_1(\lambda)$	Tritanope $\bar{t}_2(\lambda)$
400	0.0408	−0.0036	0.0407	−0.0145	0.0004	0.00084
10	0.125	−0.0108	0.124	−0.0446	0.0012	0.00190
20	0.388	−0.0330	0.387	−0.137	0.0044	0.00190
30	0.832	−0.0652	0.830	−0.274	0.0153	−0.0152
40	1.048	−0.0678	1.047	−0.286	0.0343	−0.062
50	1.063	−0.0434	1.062	−0.185	0.0611	−0.137
60	1.000	0	1.000	0	0.100	−0.244
70	0.770	0.0676	0.771	0.333	0.146	−0.329
80	0.483	0.155	0.487	0.831	0.207	−0.369
90	0.272	0.258	0.279	1.466	0.289	−0.386
500	0.153	0.406	0.163	2.422	0.426	−0.416
10	0.079	0.624	0.095	3.875	0.638	−0.435
20	0.0252	0.856	0.0469	5.554	0.862	−0.310
30	0	1.000	0.0253	6.814	1.000	0
40	−0.0147	1.061	0.0122	7.613	1.054	0.427
50	−0.0214	1.051	0.0052	8.021	1.036	0.949
60	−0.0225	0.984	0.00233	8.116	0.960	1.563
70	−0.0205	0.860	0.00126	7.878	0.828	2.229
80	−0.0165	0.694	0.00102	7.327	0.653	2.870
90	−0.0122	0.507	0.00066	6.508	0.461	3.365
600	−0.0080	0.336	0.00048	5.544	0.287	3.588
10	−0.0050	0.202	0.00018	4.510	0.155	3.450
20	−0.00277	0.114	0.00012	3.471	0.073	2.973
30	−0.00150	0.059	0.00000	2.442	0.0281	2.250
40	−0.00074	0.0289	0.00000	1.626	0.0074	1.576
50	−0.00035	0.0136	0.00000	1.000	0	1.000
60	−0.00016	0.0064	0.00000	0.572	−0.00154	0.582
70	−0.00008	0.00297	0.00000	0.301	−0.00123	0.309
80	−0.00004	0.00142	0.00000	0.160	−0.00083	0.166
90	−0.00002	0.00063	0.00000	0.077	−0.00046	0.0803
700	−0.00001	0.00030	0.00000	0.0386	−0.00025	0.0404

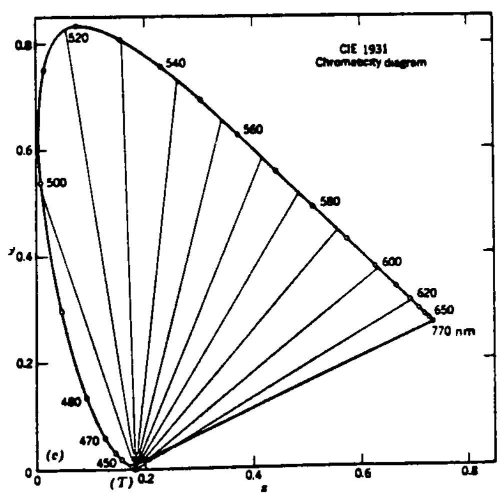
Table 1: Color-Matching Functions for Dichromats



Protanope



Deuteranope



Tritanope

Figure 3: Confusion Lines for Dichromats

of the spectrum. Dalton is a good example of this deficiency.

Deuteranopes have a similar luminosity function to normal observers but have difficulty seeing green. They lack green-sensitive cones and respond only to the blue and red content of light. The bright point for a deuteranope is 560nm, with a neutral point between 495-505nm. See table #2 for a comparison of the salient properties of color defectives.[18]

Tritanopes and tetartanopes are yellow-blue blind with a different distribution of response to the spectrum. Tritanopes have a neutral point (gray area) at 570nm, whereas tetartanopes have two neutral points, at 470nm and 580nm. They see red at the short wave, then a neutral area, followed by green, and another neutral point ending with red at the long wave end. Tritanopes and tetartanopes are both rare cases as indicated in figure #4. Protanopes and deuteranopes are the more common dichromatic deficiencies found.

Monochromatism is the last major catagory of color deficiencies and as the names implies, monchromats only have response to one primary. They can discriminate only between light-dark and shades of gray. The luminosity function is similar to the normal dark-adapted observer. Colors are matched by adjusting the brightness in an all neutral spectrum.

Characteristic	Protanomalous	Deuteranomalous	Protanope	Deuteranope	Tritanope	Rod-Monochromat
Color discrimination through the spectrum	Materially reduced from red to yellowish-green but to a varying degree in different cases		Absent from the red to about 520 nm	Absent from the red to about 530 nm	Absent in the greenish-blue to blue (445 to 480 nm)	No color discrimination
Neutral point (i.e., wavelength of monochromatic stimulus that matches a fixed "white" stimulus)[a]	None	None	490–495 nm	495–505 nm	568 and 570 nm	All wavelengths
Shortening of the red (i.e., reduced luminous efficiency of long wavelengths)	Yes	No	Yes	No	No	Yes
Wavelength of the maximum of luminous efficiency curve	540 nm	560 nm	540 nm	560 nm	555 nm	507 nm
CIE 1931 chromaticity of the confusion point (dichromats only)[b]	—	—	$x_{pc} = 0.747$ $y_{pc} = 0.253$	$x_{dc} = 1.080$ $y_{dc} = -0.080$	$x_{tc} = 0.171$ $y_{tc} = 0$	—
Percentage frequency of occurence[c]						
among males	1.0	4.9	1.0	1.1	0.002	0.003
among females	0.02	0.38	0.02	0.01	0.001	0.002

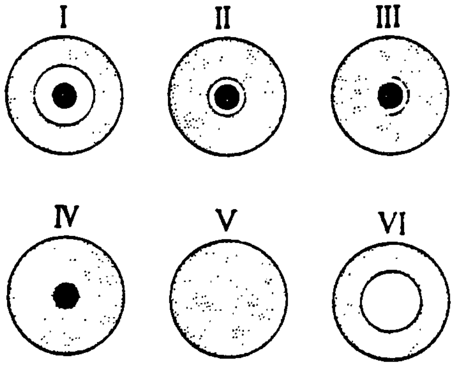
Table 2: Salient Properties of Color Defectives

E. Color Vision Tests.

In order to determine the category of a subject's disorder, a color difference test is necessary. Over the years, many various tests were developed to evaluate the various color deficiencies. The earliest tests were verbal color naming tests, which were subjective and lent themselves to deception by the observer. The following tests are also subjective, although they were designed to confuse the observer if they were truly color defective.

Maxwell's spot (1849) used a white card illuminated by incandescent light with the patterns shown in Figure #4.[19] The circular pattern is perceived differently by color defectives by altering dichroic filters (an unselective gray filter and purple gelatin filter) between the observer and the spots. Normal observers see a red or pink spot; protanopes see blue or dark spots; deuteranopes see no spot; and protanopes see blue, red or dark.[20]

Other tests that were used are the confusion charts of Stilling's (1878) and Nagel's (1898).[21] Stilling's confusion charts were based on Hering's theory of four primaries. He also developed " ...the vanishing pattern...where the color normal sees a pattern and the color defective does not."[22]



Patterns of "Maxwell's spot" as it appears to normal observers.
I : halo, clearing, central spot
II : halo, narrow clearing, central spot
III : halo, cut-up clearing, central spot
IV : halo, no clearing, central spot
V : homogeneous disc
VI : halo, clearing, no central spot

Figure 4: Maxwell's spots

Ishihara and the American Optical Society charts are the most common. A symbol or character of another hue is imbedded in the field of colored dots. Depending on the combination of the field and character hues, the various color deficiencies can be evaluated. In the 6th series of the Ishihara charts, plate #12 has a "26" on it and plate #13 has a "42" on it. The "2" and "4" respectively are red dots and the "6" and "2" are purple/red dots both with surrounds of gray dots. A deuteranope will read only the red dots, and therefore will report seeing the "2" on plate #12 and the "4" on plate #13. A protanope conversely will read only the purple and reports seeing a "6" on plate #12 and a "2" on plate #13. The Ishihara test gives no

quantitative distinction as to the degree of the deficiency. Additionally, there is no provision to explore more closely a deficiency once one has been detected. Subjects have been known to 'learn' the test and subsequently pass future testings.

The Nagel Anomaloscope (1907), a modified version of an instrument designed by Rayleigh, was also used to detect vision disorders. The instrument used a prism to split white light into the spectrum. Using optics, the eyepiece was then half illuminated with yellow light and the half with red and green. The subject would then adjust the amounts of the red and green to produce an equivalent to the yellow half of the eyepiece.[24] This test will indicate whether or not a subject is an anomalous trichromat based on the amounts of primaries they used to mix the yellow half. This method of evaluation excludes testing for dichromatic vision.

Another popular color vision test is the Farnsworth-Munsell (F-M) 100 Hue test. Based on the Munsell color system of hues, Farnsworth created a test where the observer had to place various color caps in sequence. There are actually only 85 caps in the test divided into four groups. After the observer places the caps in their perceived order, the evaluator turns over and reads the numbers on the bottoms of the caps. The absolute difference of the cap numbers in sequence are plotted on a polar chart. The F-M 100 hue test requires lengthy testing time, yet provides accurate test results. Samples of how the results would

appear for dichromats are indicated in figure #5.[25]

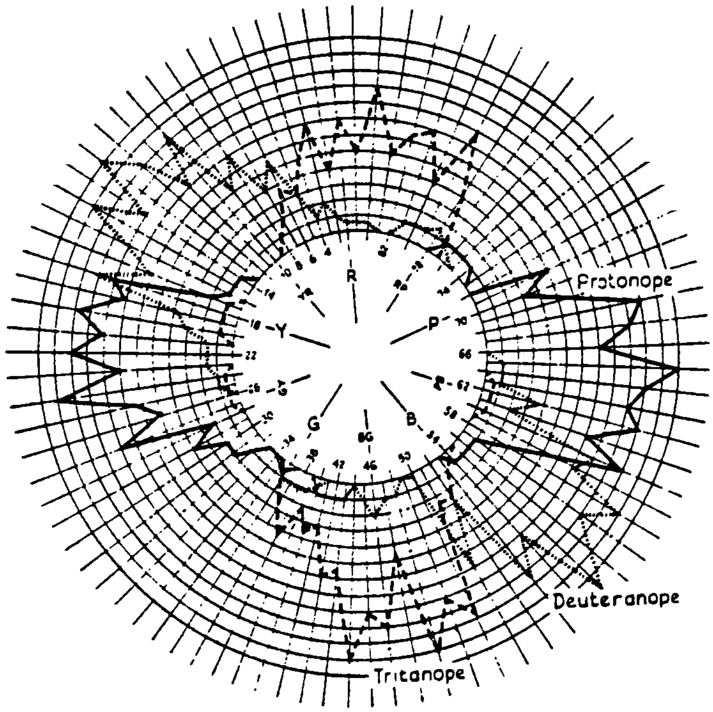


Figure 5: Defective color vision using the Farnsworth-Munsell 100 hue tests.[25]

There was not a single test available to precisely determine the color disorder until the recent development of the Lovibond Colour Vision Analyzer.[26] Utilizing the Lovibond glasses or color filters and a special optical system, the analyzer can produce a complete hue circle of any saturation. The subject is tested similarly to the Nagel Anomaloscope. The long testing time, machine availability, and cost have limited the Lovibond's wide use.

F. The Proposed Computer Color Vision Test.

Murray, after fifteen years of research and testing, suggests that the ideal screening test "...should not only identify the normal-visioned; it should if possible single out the totally color-blind, the R-G blind, and the R-G weak, the B-Y blind and B-Y weak."[27] Dimmick outlines that a color vision test should be quantified according to accepted color specifications, the test materials should sample all the visual hues, and of great practical importance is its time of administration.[28] Farnsworth states that, "If the test is to receive general usage it should be inexpensive, reproducible, and transportable.[29]

The development of a computer controlled color vision test could provide many advantages over current tests, such as the ease of administration, short testing times, and reproducibility. Since the development of the test is based on CIE 1931 standard color specifications; quantitative measurements, adaptation to a particular deficiency, and possibly a method to quantify results for classifing degrees of deficiencies may also be achievable with this type of system. Because of such possible benefits, it is worthwhile to test the feasibility of using a calibrated color monitor controlled by a computer for color vision tests.

The ability to accurately and repeatably measure the spectral output of color CRTs is essential to the creation of such a test. Spectroradiometers can perform this task

quite effectively. Since the colors on a CRT can be easily changed and measured, a CRT could provide the hardware necessary for a real-time testing system.

The investigation made during this research project was designed to test the feasibility of a calibrated color computer system and perform color vision tests. The color gamut of the system was evaluated to indicate whether or not enough colors could be produced for the precise control necessary for creating confusion colors. Using the possible colors of the system, a color vision test was programmed and compared to the results from the subject's performance using the Ishihara chart test.

II. EXPERIMENTAL.

A. Description of Equipment Used.

The computer system used for this experimentation was an Atari 800XL home computer equipped with a Sakata 13" color composite monitor and an Indus GT disk drive for storage. This system was chosen due to its low cost, ability to create the most colors of any computer in its price range, and the its availability. The spectroradiometer used to calibrate the CRT was provided by the Munsell Color Science Laboratory at Rochester Institute of Technology as is described further on. In addition to the spectroradiometer, a photometer called the Spectra Spotmeter by Photo Research was used to provide numerous measurements of the various colors during the color vision tests. The calibration and use of the Spectra Spotmeter is described in detail section C.

B. Calibration of the Color Monitor.

The Sakata color monitor in the computer system is the only source used during testing. The colors produced on the CRT's screen must be accurately known. In order to calculate chromaticity coordinates of the colors in terms of the CIE 1931 standard observer, the spectral output of the CRT was determined using a spectroradiometer. The chromaticity coordinates of the CRT's white screen were then

computed using a computer program developed at the Munsell Color Science Laboratory at the Rochester Institute of Technology. The spectral values of the CIE 1931 standard observer, and the spectral power distribution of the source, in this case the CRT, were used in the equations in appendix A.[30]

The measurements of spectral power distribution were made using a spectroradiometer constructed by the Munsell Color Science Laboratory. The system was constructed using an Oriel Detection System and a UDT detector attached to a Schoeffel monochromator. The Oriel radiometer was interfaced to a Digital Equipment Corporation LSI-11 computer which also controlled a stepping motor attached to the monochromator. The color monitor was placed on the optical bench directly in front of the entrance slit of the monochromator. The monitor was then illuminated with an all white screen and was scanned from 380nm to 760nm at 10nm intervals. From the current values collected, the spectral irradiance (in units of microwatts per centimeter squared), was calculated, and subsequently the chromaticity coordinates of the white screen were determined. These chromaticity coordinates could then be used in calibrating the Spectra Spotmeter for numerous measurements of the colors of the monitor.

C. Calibration of Spectra Spotmeter.

The ability to make repeated measurements of colors on the CRT was simplified by using a Spectra Spotmeter manufactured by Photo Research (see Appendix B). The spotmeter could provide absolute chromaticity coordinates if calibrated to a standard source. In this case, the standard source was considered the white screen generated by the color monitor. Since the chromaticities were computed accurately using a spectroradiometer, other colors on the screen could be measured and compared relative to the white standard. The following equations were taken from the Spectra Spotmeter's manual and used for calculating the calibration constants necessary for computation of chromaticities of other colors.[31]

$$C1 = x/y * P/R \qquad (1)$$

$$C2 = (1-x-y)/y * P/B \qquad (2)$$

In the above equations, x and y are the CIE chromaticity coordinates computed for the standard white screen. The initials P, R, and B represent respectively the photopic, red, and blue meter values measured using the Spectra Spotmeter. Once the calibration constants C1 and C2 are computed, chromaticities of unknown colors can be calculated using the following equations by just entering the measured values of P, R, and B:

$$x = RC1 \ / \ (RC1 + P + BC2) \qquad (3)$$

$$y = P \ / \ (RC1 + P + BC2) \qquad (4)$$

D. Computer Programs for Measurements and Testing.

Three programs where necessary for developing and running the color vision tests. The first program (see Appendix C) was written to provide a method for creating a color patch on the CRT's screen for measurement by the spotmeter. The program allows entry of the color and intensity values of the patch along with the intensity of the white surround. The color patch will remain on the screen until any key on the computer keyboard is depressed allowing another set of values to be entered.

The second program (see Appendix D) calculates the chromaticity coordinates upon entering the P, R, and B meter values. The program includes the C1 and C2 calibration constants and uses equations 3 and 4 for the chromaticity calculations.

The last program (see Appendix E) randomly generates three test patches, using colors entered by the test administrator. In order to simplify the programming aspect of the project, stripes were recommended.[32] The stripes would be assigned to different colors (see Appendix F).

E. Measurement of the CRT's Color Gamut.

Once the calibration of the CRT and the spotmeter were performed and the computer programs written, the color gamut of the computer-monitor system was measured and plotted on the CIE chromaticity Diagram. The various colors were then compared to the confusion lines explained by Judd and Wyszecki,1975. By comparing the location of the colors confused by the subjects on the chromaticity diagram, the type of deficiency could be determined based on which confusion lines they intersected. Most of the confusion color pairs that were possible generate with the system were used in testing the subjects.

F. Visual Experimentation.

There were two stages to the testing of the subjects. The first stage involved testing the subject with Ishihara Charts (series #6) and evaluating the results. The Ishihara test was administered in a Macbeth Illumination hood set at 5000K. The Ishihara test requires daylight illumination and the Macbeth hood provided the closest approximation. The first thirteen plates were used. The first plate is a demonstration plate and was used to explain the testing procedure to the subject. Subsequent plates were placed in front of the subject for approximately ten seconds and their

response recorded. At the end of the testing period, any plates that caused difficulty were reviewed.

The second phase of the visual experimentation involved administering the test developed using the calibrated CRT. The color vision test using the CRT involved the subject sitting approximately four feet from a 13" monitor. A dull tungsten light directly above the system was the only other illumination in the room. The light was necessary for providing the test administrator with illumination for writing down the subject 's responses. No glare from this light was created on the screen. The testing patch consisted of a 4 by 5 inch color patch surrounded by a white field.

The assumption was made that a constant white surround would minimized the complicated question of chromatic adaption. The surround was kept at a constant intensity since it is extremely difficult to measure and specify the chromatic adaptation for each subjects.[33] This would help eliminate the subject's decision being based on perceived color differences every time a new pair of colors were placed on the screen. The color patch was visible for approximately ten seconds to the subject, after which it disappeared and the subject gave their response to the color pair. Results of the computer test were then evaluated and, if necessary, other color pairs were entered into the program as testing continued.

III. RESULTS.

A. Source Chromaticities:

Tristimulus Values:

X: 1.02991
Y: 1.00000
Z: 1.59053

Chromaticity Coordinates:

x = 0.2844700
y = 0.2762095
z = 0.4393204

These chromaticity values are for the Sakata monitor and were calculated from the measured spectral irradiance values of the white screen.

B. Calibration Constants:

Source Chromaticities: x = 0.28447
y = 0.27621

Spotmeter Values: P = 278
R = 136
B = 828

C1 = x/y * P/R
= (1.0299)*(2.0441)
C1 = 2.105

C2 = (1-x-y)/y * P/B
= (1.5905)*(0.3357)
C2 = 0.534

The spotmeter values were obtained by measuring the Sakata white screen at the same time the monitor was calibrated. The calibration constants were then used in program #2 for calculating chromaticities of the unknown colors.

File Description : SAKATA COLOR- MIDDLE

Wavelength Increment : 10 nm

File Data (wavelengths in nm)

380>	0.0062	480>	0.0467	580>	0.0275	680>	0.0067
385>	0.0000	485>	0.0000	585>	0.0000	685>	0.0000
390>	0.0079	490>	0.0426	590>	0.0233	690>	0.0271
395>	0.0000	495>	0.0000	595>	0.0000	695>	0.0000
400>	0.0145	500>	0.0433	600>	0.0268	700>	0.0245
405>	0.0000	505>	0.0000	605>	0.0000	705>	0.0000
410>	0.0259	510>	0.0468	610>	0.0691	710>	0.0051
415>	0.0000	515>	0.0000	615>	0.0000	715>	0.0000
420>	0.0438	520>	0.0489	620>	0.0756	720>	3.829E-04
425>	0.0000	525>	0.0000	625>	0.0000	725>	0.0000
430>	0.0591	530>	0.0491	630>	0.0252	730>	3.171E-04
435>	0.0000	535>	0.0000	635>	0.0000	735>	0.0000
440>	0.0747	540>	0.0452	640>	0.0033	740>	3.410E-04
445>	0.0000	545>	0.0000	645>	0.0000	745>	0.0000
450>	0.0762	550>	0.0382	650>	0.0020	750>	2.399E-04
455>	0.0000	555>	0.0000	655>	0.0000	755>	0.0000
460>	0.0684	560>	0.0306	660>	0.0017	760>	3.726E-04
465>	0.0000	565>	0.0000	665>	0.0000		
470>	0.0573	570>	0.0263	670>	0.0026		
475>	0.0000	575>	0.0000	675>	0.0000		

Table 3: Spectral Radiance Values of Sakata's white screen

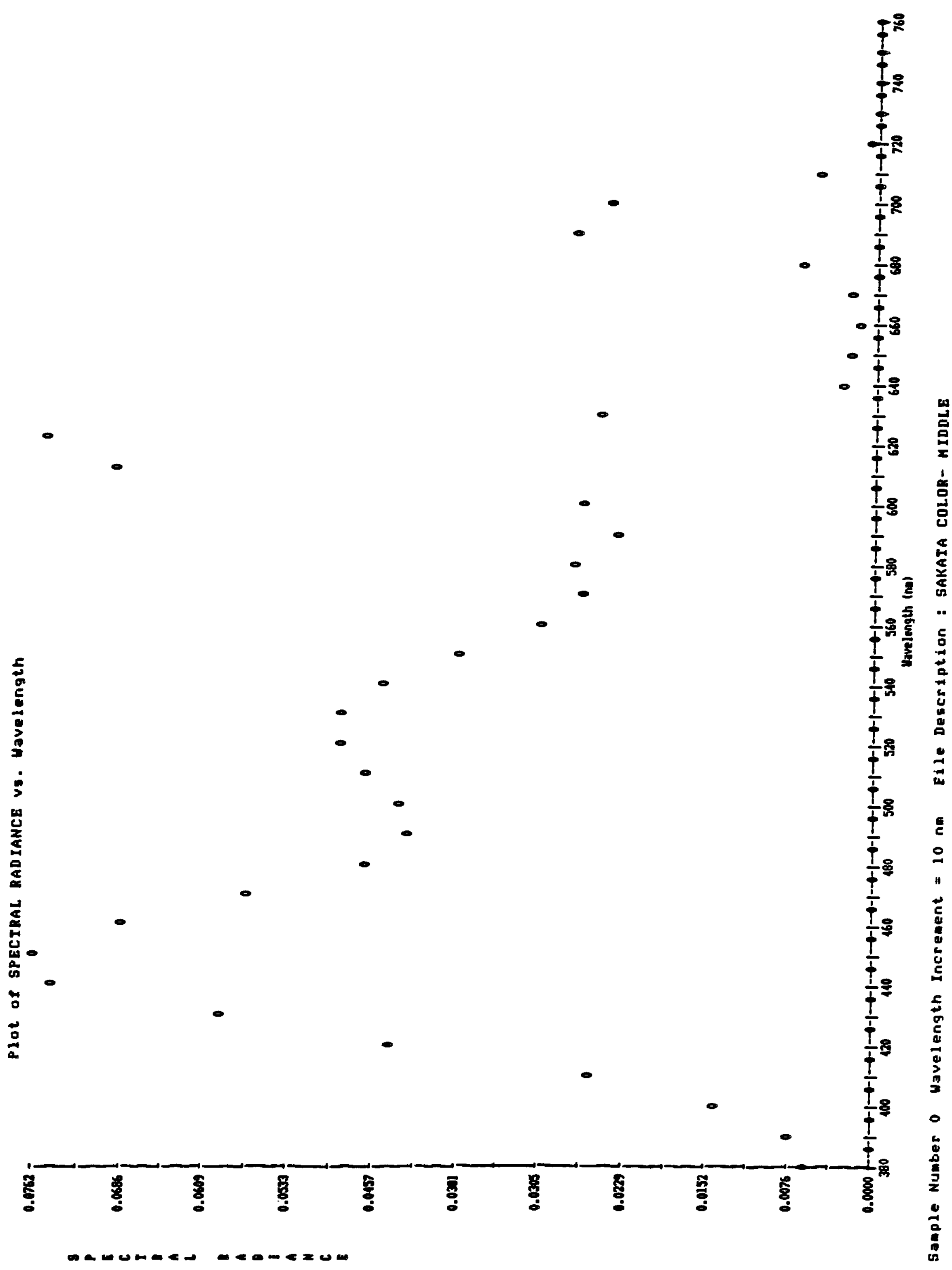


Figure 6: Plot of Spectral Radiance vs. Wavelength (Sakata)

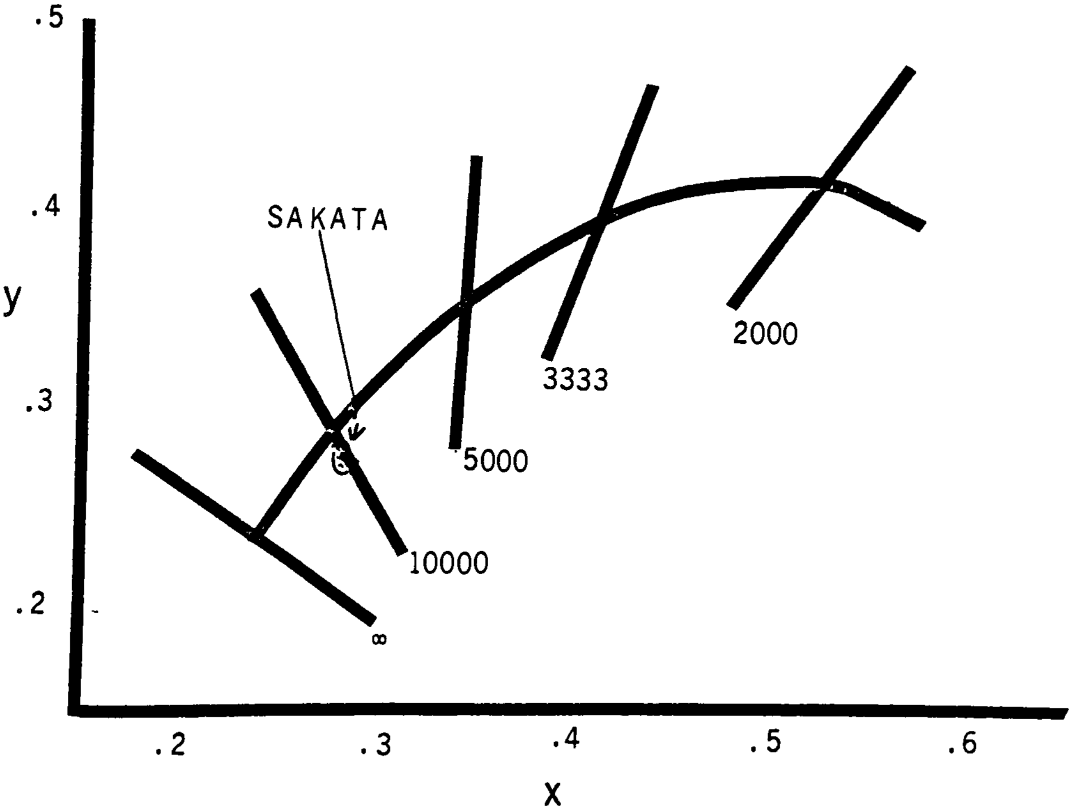


Figure 7: Chromaticity plots of Sakata's white screen

Photopic Values

C#,I#\ S.I.	0	2	4	6	8	10	12	14
3.6	1.41	1.28	1.15	1.0	.91	.74	.60	.35
7,6	1.25	1.15	1.00	.88	.78	.66	.50	.27

Red Values

C#,I#\ S.I.	0	2	4	6	8	10	12	14
3,6	1.03	.93	.86	.77	.70	.62	.53	.33
7,6	.51	.44	.38	.32	.27	.22	.17	.08

Blue Values

C#,I#\ S.I.	0	2	4	6	8	10	12	14
3,6	2.55	2.15	1.84	1.47	1.26	.96	.65	.27
7,6	8.50	7.80	7.40	6.70	6.20	5.70	4.85	3.30

C# = color number as defined by Atari
I# = intensity level
S.I. = surround intensity level

Table 4: Measured Effect of Surround on the Color Patch

The changes of intensity of the white surround were varied from 0 to 14 for a red colored patch(#3) and a blue colored patch(#7). The patches were measured using the spotmeter and recorded for the three filter settings of Photopic, Red and Blue.

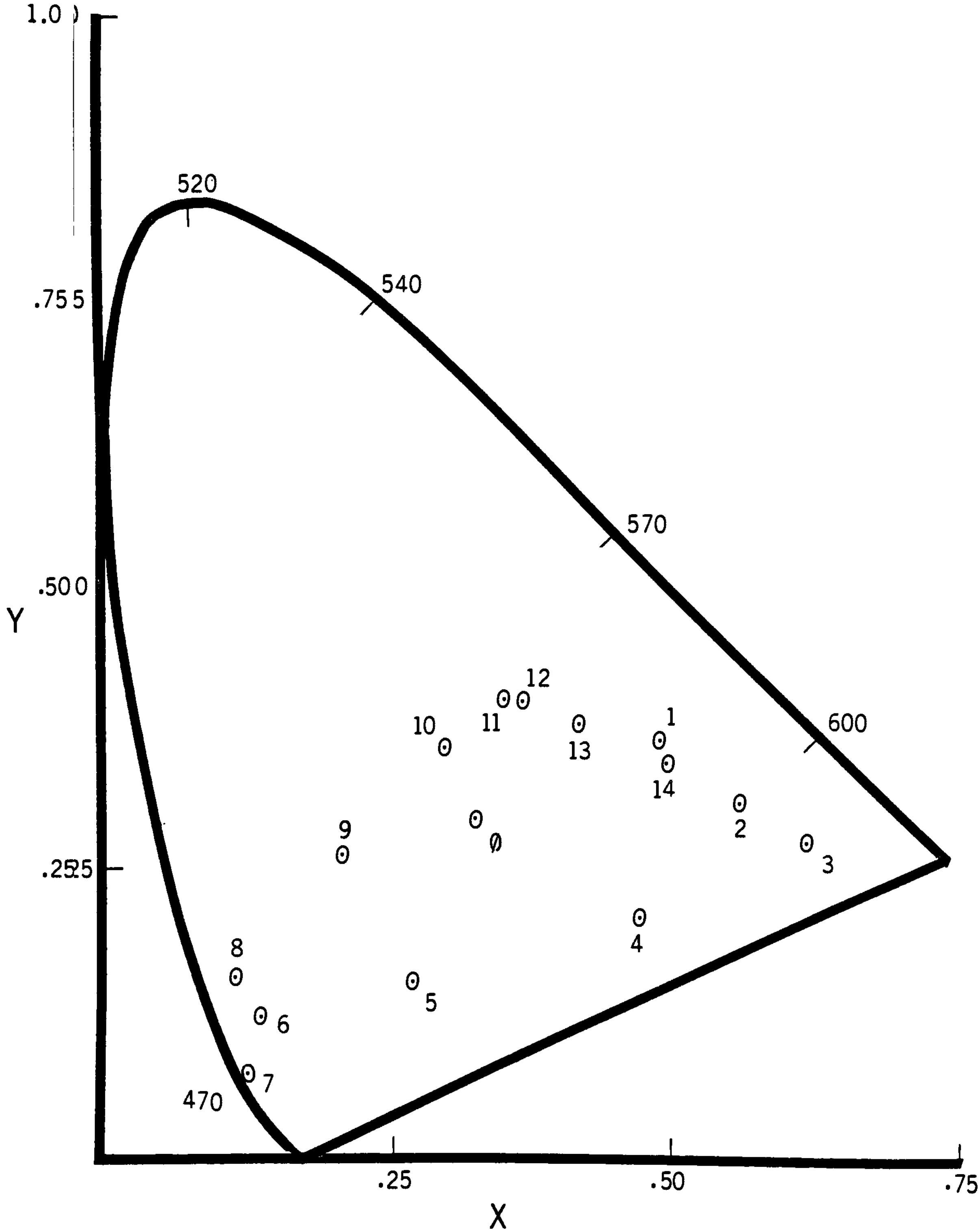


Figure 8: CIE Chromaticity Diagram of Color Gamut of Atari System

ISHIHARA TESTS

Plate #	Normal Response	Subject#1	2	3	4	5
1	12	C	C	C	C	C
2	8	C	3	3/8?	3	3
3	6	C	5	5	5	5
4	5	C	2	2	2	2
5	74	C	21	21	21	21
6	2	C	N	N	N	N
7	6	C*	N	N	N	N
8	5	C	N	N	N	N
9	7	C	N	N	N	N
10	lines	?	N	5?	5?	5?
11	lines	?	2	2	2?	2?
12	26	C*	2only	6only	2only	2only
13	42	C	4only	2only	4only	4only

C means a correct response was given by subject.
N means no response was given by subject.
? means the subject was not sure what they saw.
C* means the subject did see a number yet thought it was gray.
'Only' indicates subject saw the one number listed and not the other.

Table 5: Responses to Ishihara Tests

Subject # \ Color #	0	1	2	3	4	5	6	7	8	9	10
1			B						B	B	
2	B								B	B	
3				C	C	C			A	A	A
4	B		B						B	B	
5									B	B	B

A = confused color with gray
B = confused color with green
C = confused color with blue

Table 6: Confusion Colors of the Subjects

This table indicates which colors a subject confused and gave an incorrect response. The color numbers coorespond to the Atari numbering system for the colors (see table #7). The areas that are blank indicate the subject had no difficulty with the appropriate color.

The confusion pairs that are shown on the following figures #9 and #10 indicate two colors which when placed on the screen appear to be the same for the subject with the appropriate deficiency. The color pairs coorespond with the following color numbers:

A = #8 , #5
B = #9 , #4
C = #2 , #3
D = #1 , #2
E = #5 , #4
F = #4 , #3

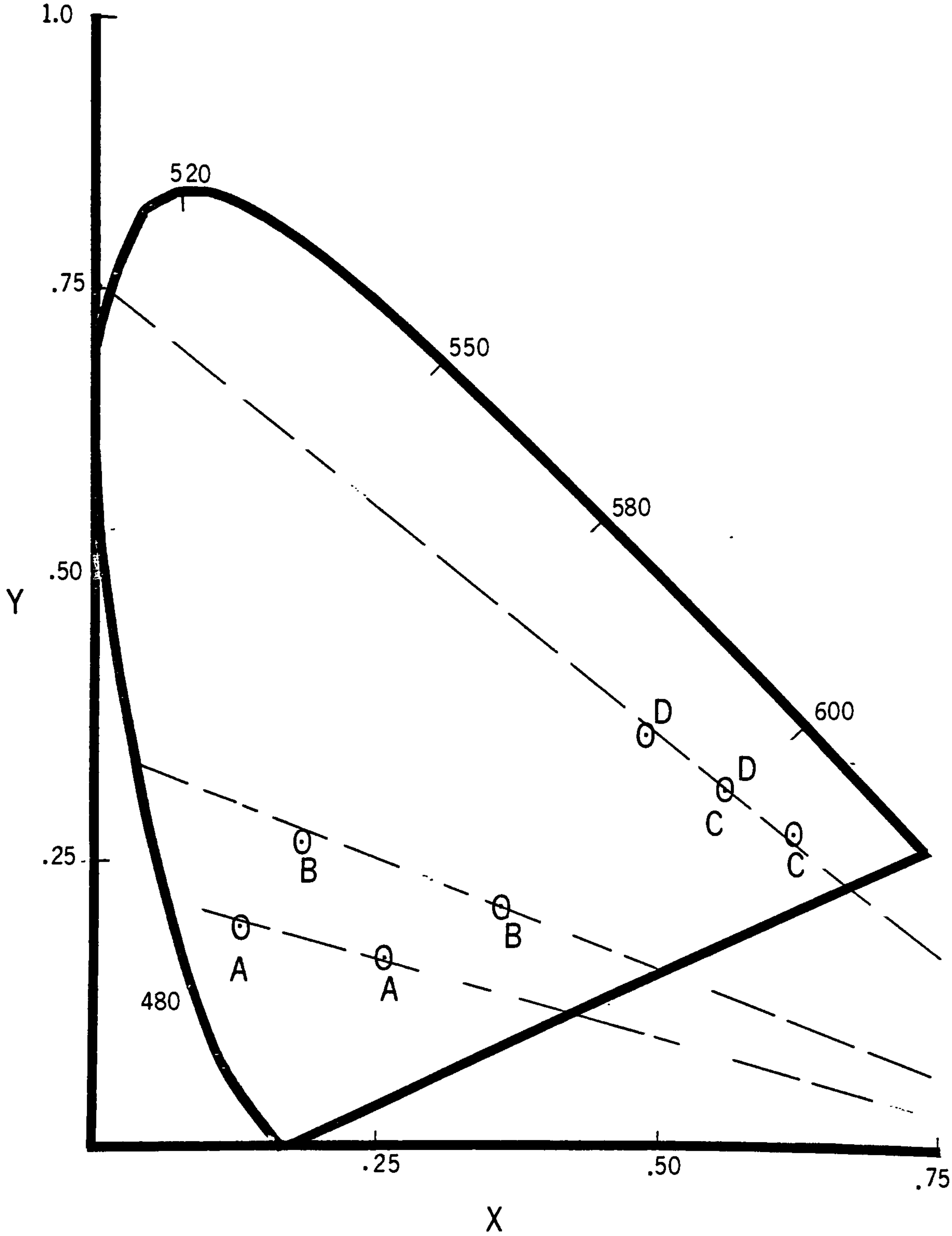


Figure 9: Confusion pairs of Deuternopes

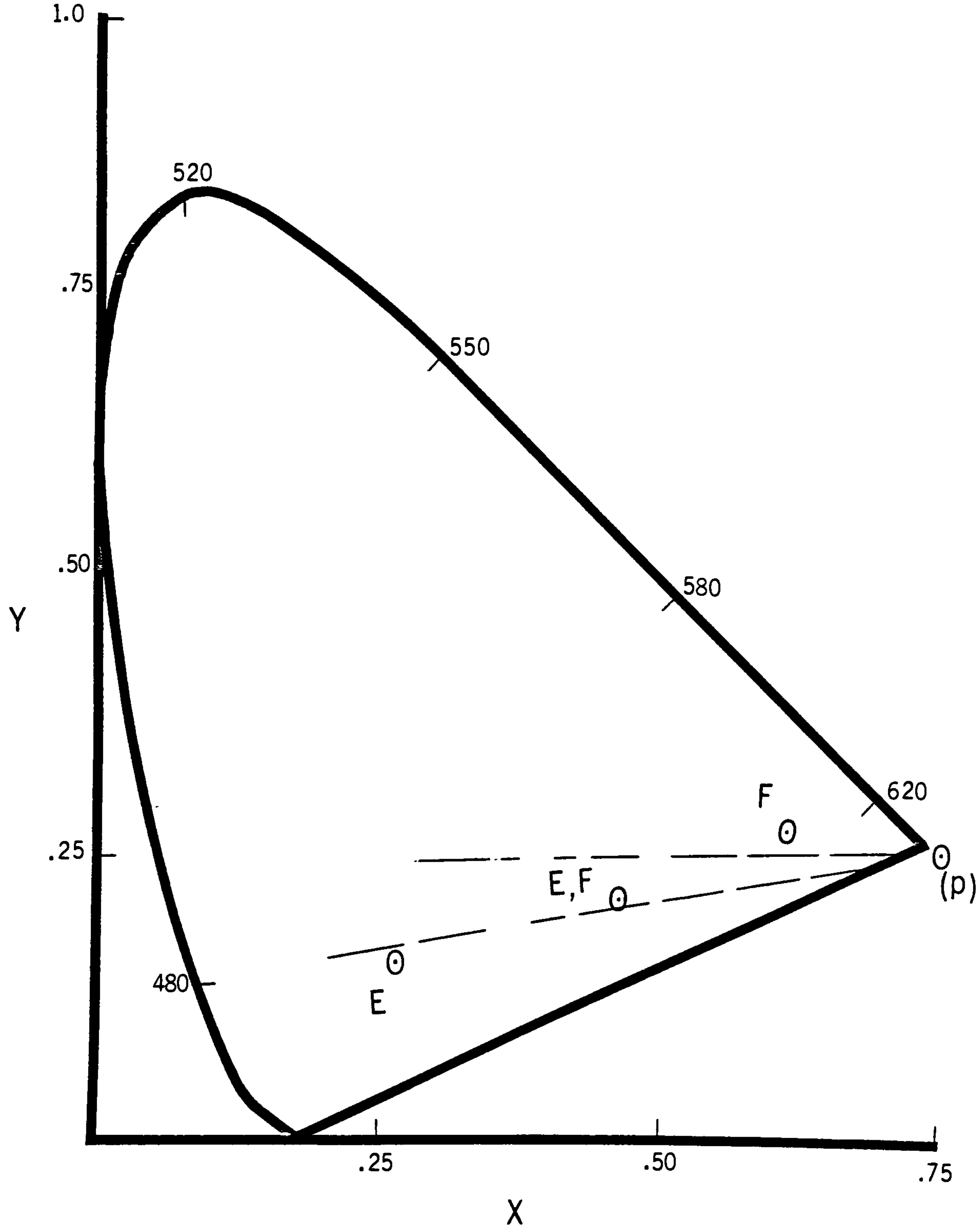


Figure 10: Confusion pairs of Protanopes

IV. DISCUSSION.

The calibration of the CRT, in this case the Sakata monitor, was performed by measuring the spectral radiance of the white screen as is listed in Table #3. From these values, the chromaticity coordinates were calculated and plotted on the CIE 1931 chromaticity diagram with the Planckian Locus added to the diagram (see figure #7). The correlated color temperature was calculated to be approximately 10,000 degrees Kelvin. The spectral power distribution plot for the monitor is shown in figures #6. The Atari/Sakata system peaked at 450nm, 525nm, and 620nm for blue, green, and red, respectively. The Atari 800XL computer can generate the following colors which are assigned the numbers 0-15.[34] The sixteen colors can also have their intensities changed over eight levels.

Number	Color	Number	Color
0	Grey	8	Light Blue
1	Gold	9	Blue-Green
2	Orange	10	Aqua
3	Red	11	Green-Blue
4	Pink	12	Green
5	Violet	13	Yellow-Green
6	Blue-Purple	14	Orange-Green
7	Blue	15	Orange

Table 7: Colors on Atari 800XL Computer[34]

These colors were all produced on the screen in the 4x5" patch and measured. Their chromaticites were calculated and

were plotted on the CIE 1931 chromaticity diagram as shown in figure #8. Only the colors measured at brightness level four are indicated since they show the largest area or gamut that can be created. All the colors appear black when the brightness level was at zero or two. As the intensity was increased, the colors converged towards the center of the diagram.

The effect of the surround brightness on color patch was measured and indicates that the brightness of the color patch does change as the brightness of the surround changes. In each case tested, the effect is constant and the system responds linearly. The patch's brightness decreases steadily as the surround brightness increases (see Table #4 for values). For this reason, the surround was set at brightness level twelve throughout the color vision tests for consistency.[35]

The subjects were tested initially with the Ishihara Charts and the results are reported in table #5. Using the responses from plates #12 and #13 as indication of the type of dicromatic vision, subjects numbered 2, 4, and 5 were considered deuteranopes. Subject #3 was considered a protanope. Subject #1 is considered to be a deuteranope, however, it is a slight deficiency.

Using the color vision test with the computer, the results in table #6 indicate the colors confused by each subject. In very instance, the subjects were able to distinguish the stripes which could be accountable to an alignment problem with the CRT's electron guns. If the guns

are not aligned properly, sharp edges are not obtainable therefore creating an edge effect visible due to the intensity change. An interesting occurrence was that subjects would report seeing different colors redefining the spectrum. They all appear to have adjusted to their deficiencies and associate different colors to parts of the spectrum representing the colors they theoretically cannot see. For instance, a protanope having a shortening of the red end of the spectrum reports seeing blue and the blue wavelengths appear gray. The deuteranopes having diffuculty seeing the green part of the spectrum have associated green to parts of the blue spectrum. Also areas of the red spectrum appear green to the deuteranopes due to reduced amount of red they see. Any grays were considered blue by deuteranopes.

Confusion pairs (two different colors that appear the same to the subject) were plotted on the CIE chromaticity diagram as shown in figure #9 for deuteranopes and figure #10 for protanopes. A line is drawn through the two confusion pairs, which converges on the theoretical confusion point. If the colors could be controlled to even finer proportions, then it could be possible to confirm Pitt's[36] work.

There were no difficulties in calibrating the color CRT before testing and the colors were able to be reproduced repeatedly between sessions. The results from the Ishihara test did agree with the color vision tests with the color

monitor system. The limitation on the number of colors that the computer system could generate did not limited the ability to diagnose the type of deficiency. The ability to create even more colors would just increase the opportunity to quantify the results for degrees of deficiency. The color vision test with the computer could even evaluate subject #1 who had the slightest deficiency. The system did have the problem of creating green colors and is evident since the color vision tests with the monitor did not create any confusion colors that were green. Instead, the subjects confused grays and blues with green.

V. CONCLUSIONS.

Color vision tests using a calibrated color monitor did prove to be a feasible testing method even with the apparent equipment limitations. The ability to measure the colors on a CRT reproducably was possible and did provide the necessary information in developing the computer test. The difficulties in making such a test wildly acceptable lie in developing a computer system which can create enough colors necessary for complete evaluation of all possible deficiencies.

The Atari/Sakata system was not able to produce a wide enough selection of greens. This was limited due to the CRT's spectral power distribution. It has been verified that CRT's use larger amounts of blue then the other primaries. The Atari computer boasts the capability of creating 256 colors, yet the intensity settings of zero and two are useless. The intensity level #14 is too bright and hurts the eyes. If the computer could be altered to actually control the electron guns and not just change factory settings, then it may be possible use this inexpensive system on a large scale just by calibrating each computer/monitor system.

A major advantage to the computer test was the ability of the administrator to vary the colors while testing, thus allowing for creating a large number of testing combinations and not just be limited to 16 plates as in the Ishihara

test. The ability to change the colors also helps eliminate the subject's attempt to learn the tests and pass future testings. Since the computer system acted as the source for the test patches, the problem associated with not have proper viewing conditions was avoided.

The major disadvantage to the system was that the program was not able to evaluate for anomalous trichromats. Anomalous trichromats account for 75 percent of the all color defectives. A possible test could be developed which let the subject mix and match colors similarly to the anomaloscope. Since, the control of the colors was limited with this system, weak deficiences such as subject #1 were hard to detect. Overall, the test was successful in discriminating between trichromats and dichromats along with which type of dichromatism the subject had.

Future work should concentrate on creating more colors another system and designing the test to detect anomalous trichromats. The test should also be performed with more subjects so a statistical model could be used to evaluate the accuracy of the computer test. The number of subjects was limited in this project since the testing was intended to concentrate on small number of known defectives and to test the feasibility of performing color vision tests with a calibrated color monitor. The test was being developed and was not in a finished form for testing a quantity of subjects.

Additionally, a more appropriate testing pattern should be designed in order to avoid sharpness and edge effects

which made the stripes visible in every test. The use of the vanishing pattern effect similar to the Ishihara test may be a possible alternative.

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APPENDICES

APPENDIX A.

Calculation of Tristimulus Values and Chromaticity Coordinates

$$X = k \int \phi(\lambda)\ \bar{x}(\lambda)\ d\lambda$$
$$Y = k \int \phi(\lambda)\ \bar{y}(\lambda)\ d\lambda$$
$$Z = k \int \phi(\lambda)\ \bar{z}(\lambda)\ d\lambda$$

where k equals the normalizing factor and was 680 lumen per watt based on the maximum luminous efficacy of the standard observer. The object-color stimulus $\phi(\lambda)\ d\lambda$ was considered the spectral power distribution of the source. The tristimulus values were approximated by summation using the weighted-ordinate method. The chromaticity coordinates were calculated as follows:

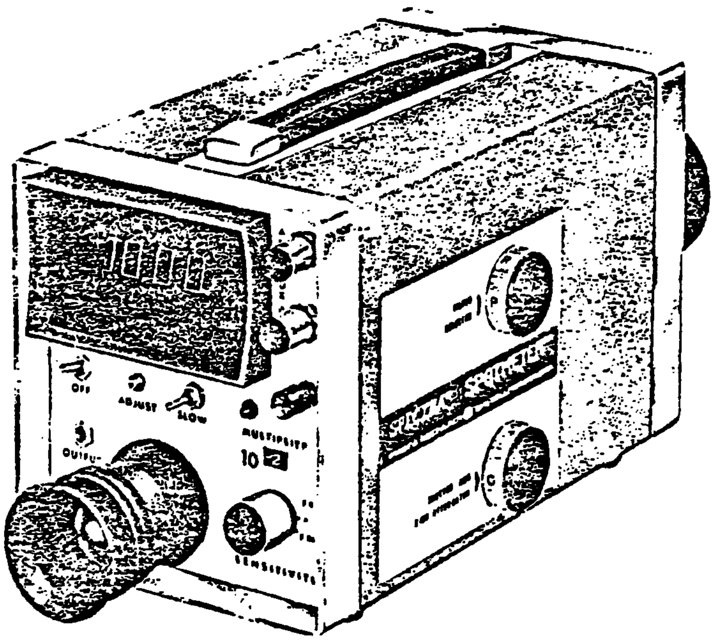
$$x = X / X + Y + Z$$
$$y = Y / X + Y + Z$$
$$z = Z / X + Y + Z$$

APPENDIX B.

Spectra Spotmeter by Photo Research

SPECTRA® SPOTMETER™

MODEL UBD



Typical Applications

- *Display Measurements*
- *Cathode Ray Tube Luminance*
- *MIL-SPEC Lighting Compliance*
- *Street and Roadway Lighting*
- *Aircraft Panel Checkout*
- *Material Reflectance Studies*
- *Automotive Lighting*
- *Color Temperature Determination*
- *Airport Lighting*
- *Air Pollution Monitoring*
- *Lamp Quality Control*

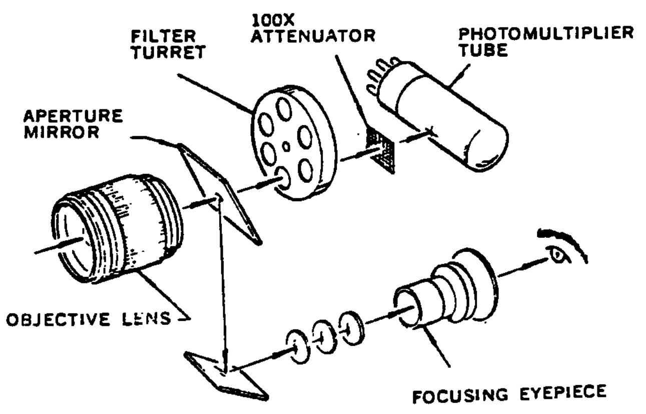
SPECTRA® SPOTMETER™

DESCRIPTION

The Spectra® Spotmeter™ consists of a unique optical system, an unusual objective lens, a solid-state electronics package and a readout indicator — all in one compact package.

OPTICAL SYSTEM

The unique optical system of the Spectra® Spotmeter™ is shown below. The objective lens forms a real image at the aperture of a metallic mirror. The photons being measured pass through the aperture to the photomultiplier tube, while the mirror surface reflects the balance of the incoming light to the viewing system. Thus the operator sees a bright, erect, magnified image with a small, circular black spot in the center; this black spot clearly and accurately defines the measuring field. This optical system provides a *bright, unambiguous viewing field* with *precise location* of the measuring field indicated within the viewing field.* Furthermore, because photons in the measuring path encounter no mirrors, beamsplitters, or fiber optics, this optical system is *completely free of polarization error.**



OPTICAL SYSTEM

OBJECTIVE LENS

The standard objective lens with the Spectra® Spotmeter™ is the new Macro-Spectar™ lens. This high-resolution, low-flare lens can be focused from *2½ inches to infinity*, thus enabling the instrument to be used for either microphotometry or telephotometry with *no accessory lenses or changes in calibration!*

*For a detailed discussion of the optical system, see "Optical Systems for Defining the Viewing and Measuring Fields in Luminance/Radiance Meters" by Richard A. Walker, *Applied Optics*, Volume 11 (1972), p. 2062.

FILTER TURRET AND ATTENUATOR

A 6-position filter turret is located between the aperture mirror and the phototube. This turret contains the "photopic" filter, which modifies the spectral response of the instrument to precisely match that of the human eye; the photopic filter is *individually trimmed* and calibrated in every Spotmeter™. The turret also contains red and blue colored filters for relative tristimulus and color temperature measurements, an "Open" position for relative radiometric measurements, and an internal calibration-reference source. The internal reference source is extremely useful for field-calibration and for making periodic calibration checks without returning to a calibrating facility.

A separate control actuates an internal 100X optical attenuator for measurement of high light levels.

PHOTOMULTIPLIER TUBE

The phototube is contained in a special housing which provides shielding from electromagnetic fields. A specially selected and seasoned low-noise bialkali photomultiplier tube is standard; phototubes with increased infrared spectral response — such as S-20 tubes — are available on special order. (Note: The S-20 tube is slightly "*noisier*" than the standard phototube.) Silicon cell Spotmeters are also available. See Product Bulletin No. 526.

ELECTRONICS SYSTEM

The electronics package is a compact, all-solid-state system featuring the latest advances in integrated circuitry. The circuitry has been designed for maximum long-term stability under wide variations of temperature and humidity. The controls and readouts have been engineered for maximum accuracy and operator convenience. An analog output jack is provided for driving an external analog recorder. A B.C.D. output jack is available on special order for Spotmeters equipped with a digital readout.

READOUT INDICATORS

The Spectra® Spotmeter™ may be equipped with either a 3½-digit non-blinking digital readout or a panel meter. The panel meter is of the rugged, taut-band variety, and features a dual-range illuminated scale for maximum legibility. Illuminated readouts for "Range" and "Multiplier" indications are standard on all models.

APPENDIX C.

Calibration Routine for Creating Test Patch

```
2 REM
5 REM CALIBRATION ROUTINE
7 REM
10 PRINT "ENTER SURROUND":INPUT W
20 PRINT "ENTER COLOR":INPUT Y
30 PRINT "ENTER INTENSITY":INPUT Z
35 GRAPHICS 3+16
40 SETCOLOR 4,0,W
45 SETCOLOR 1,Y,Z
50 COLOR 2:REM FOREGROUND REGISTER
60 FOR X=10 TO 28
70 PLOT X,7
80 DRAWTO X,16
90 NEXT X
95 REM FOLLOWING OPEN STATEMENT IS FOR
100 REM KEYBOARD GET STATEMENT
110 OPEN #1,4,0,"K:"
115 GET #1,C
120 CLOSE #1
130 GOTO 20
```

APPENDIX D.

Chromaticity Calculations Using Values from the Spectra Spotmeter

```
2 REM
5 REM CHROMATICITY CALCULATIONS
7 REM
10 C1=2.105
20 C2=0.534
30 ? :? :? :? :? :? :? :?
40 PRINT "P= ":INPUT P
50 PRINT "R= ":INPUT R
60 PRINT "B= ":INPUT B
70 X=(R*C1)/((R*C1)+P+(B*C2))
80 Y=P/((R*C1)+P+(B*C2))
90 ? :? :? :?
100 ? "X=";X
110 ?
120 ? "Y=";Y
130 OPEN #1,4,0,"K:"
140 GET #1,C
150 CLOSE #1
160 GOTO 10
```

APPENDIX E.

Testing Program

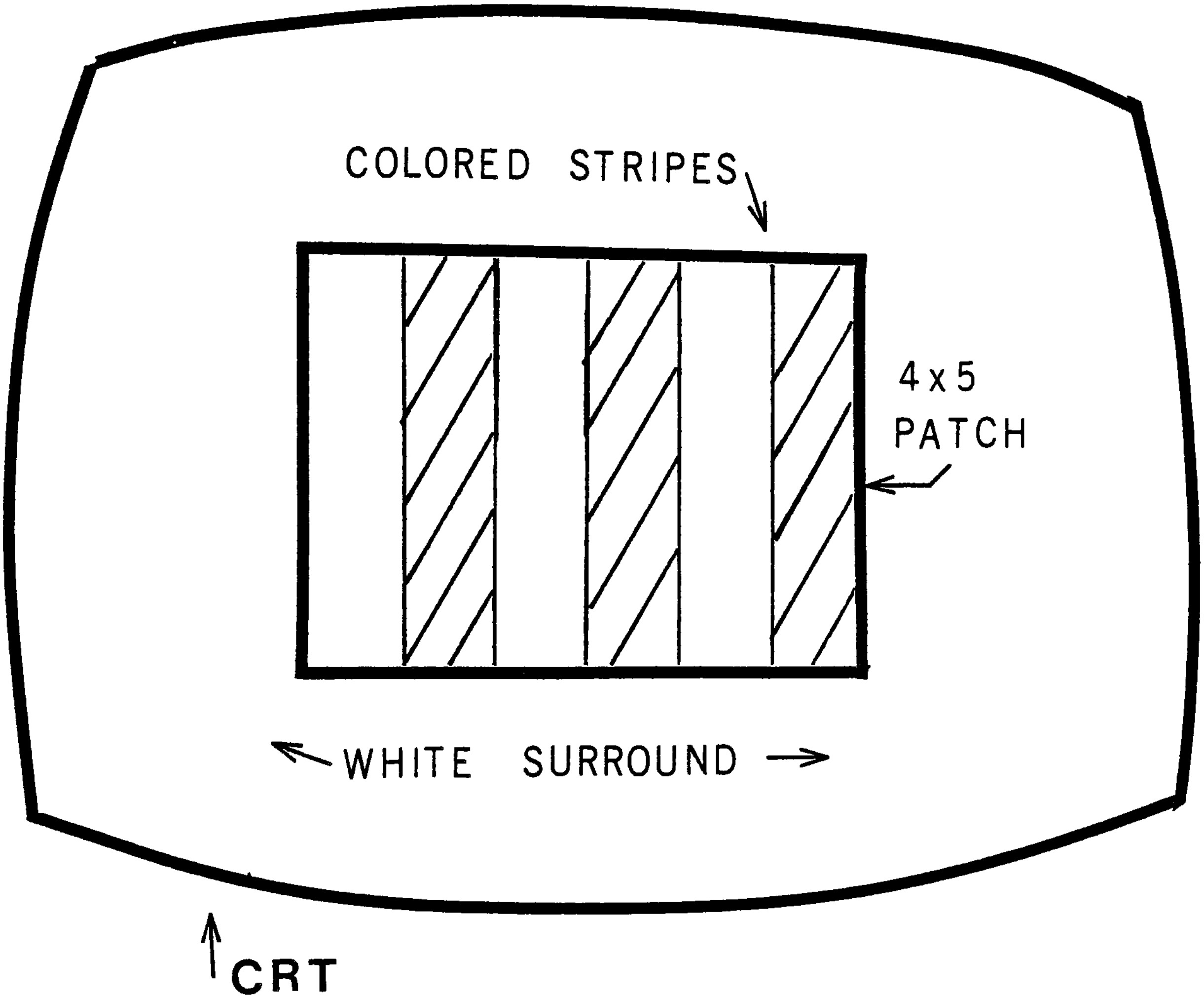
```
10 Y1=0:Y2=0:Z1=0:Z2=0
20 PRINT "ENTER COLOR PAIR # =":INPUT P
30 GOSUB 900
35 REM 900 GOES TO IF-THEN'S FOR DATA
40 R=RND(0)*10:Q=INT(R)
45 REM RANDOM NUMBER GENERATOR FOR
46 REM SELECTION OF TEST PATTERN
50 IF Q=0 OR Q=1 THEN GOSUB 5000
55 IF Q=2 OR Q=3 THEN GOSUB 5300
60 IF Q=4 OR Q=5 THEN GOSUB 5200
65 IF Q=6 OR Q=7 THEN GOSUB 5000
70 IF Q=8 OR Q=9 THEN GOSUB 5300
80 GOSUB 9000
899 GOTO 20:END
900 IF P=0 THEN GOSUB 1000
905 IF P=1 THEN GOSUB 1100
910 IF P=2 THEN GOSUB 1200
915 IF P=3 THEN GOSUB 1300
920 IF P=4 THEN GOSUB 1400
925 IF P=5 THEN GOSUB 1500
930 IF P=6 THEN GOSUB 1600
935 IF P=7 THEN GOSUB 1700
940 IF P=8 THEN GOSUB 1800
945 IF P=9 THEN GOSUB 1900
950 IF P=10 THEN GOSUB 2000
955 IF P=11 THEN GOSUB 2100
960 IF P=12 THEN GOSUB 2200
965 IF P=13 THEN GOSUB 2300
970 IF P=14 THEN GOSUB 2400
975 IF P=15 THEN GOSUB 2500
980 IF P=16 THEN GOSUB 2600
985 IF P=17 THEN GOSUB 2700
990 IF P=18 THEN GOSUB 2800
995 RETURN
996 REM
998 REM BEGIN DATA COORDINATES
999 REM
1000 Y1=5:Y2=4
1010 Z1=13:Z2=4
1020 RETURN
1100 Y1=4:Y2=4
1110 Z1=2:Z2=4
1120 RETURN
1200 Y1=11:Y2=4
1210 Z1=12:Z2=4
1220 RETURN
1300 Y1=6:Y2=4
1310 Z1=8:Z2=4
1320 RETURN
1400 RETURN
```

```
1405 REM
1410 REM 1400 IS A REPEAT LAST
1412 REM ENTERED COLORS WITH DIFF. PATTERN
1415 REM
1500 Y1=5:Y2=6
1510 Z1=12:Z2=6
1520 RETURN
1600 Y1=4:Y2=6
1610 Z1=15:Z2=6
1620 RETURN
1700 Y1=5:Y2=8
1710 Z1=12:Z2=8
1720 RETURN
1800 Y1=6:Y2=8
1810 Z1=9:Z2=8
1820 RETURN
1900 Y1=7:Y2=8
1910 Z1=8:Z2=8
1920 RETURN
2000 Y1=3:Y2=8
2010 Z1=2:Z2=8
2020 RETURN
5000 REM
5005 REM STRIPS ROUTINE BEGINS
5010 REM THIN STRIPS - TWO COLORS
5015 REM
5040 GRAPHICS 3+16
5045 SETCOLOR 4,0,12
5050 COLOR 2
5060 FOR X=10 TO 28 STEP 2
5065 SETCOLOR 1,Y1,Y2
5070 PLOT X,7
5080 DRAWTO X,16
5090 NEXT X
5095 COLOR 3
5100 FOR X=11 TO 29 STEP 2
5110 SETCOLOR 2,Z1,Z2
5120 PLOT X,7
5130 DRAWTO X,16
5140 NEXT X
5150 RETURN
5190 REM
5200 REM BOX ONE COLOR
5210 REM
5240 GRAPHICS 3+16
5245 SETCOLOR 4,0,12
5250 COLOR 2
5260 FOR X=10 TO 28
5265 SETCOLOR 1,Y1,Y2
5270 PLOT X,7
5280 DRAWTO X,16
5290 NEXT X
5295 RETURN
5300 REM
5305 REM STRIPS ROUTINE BEGINS
5310 REM THICK STRIPS - TWO COLORS
```

```
5315 REM
5340 GRAPHICS 3+16
5345 SETCOLOR 4,0,12
5350 COLOR 2
5360 FOR X=10 TO 28 STEP 4
5365 SETCOLOR 1,Y1,Y2
5370 PLOT X,7
5380 DRAWTO X,16
5390 NEXT X
5395 COLOR 2
5400 FOR X=11 TO 29 STEP 4
5410 SETCOLOR 2,Y2,Z2
5420 PLOT X,7
5430 DRAWTO X,16
5440 NEXT X
5450 COLOR 3
5455 FOR X=12 TO 29 STEP 4
5460 SETCOLOR 2,Z1,Z2
5470 PLOT X,7
5480 DRAWTO X,16
5490 NEXT X
5510 COLOR 3
5520 FOR X=13 TO 30 STEP 4
5530 SETCOLOR 2,Z1,Z2
5540 PLOT X,7
5550 DRAWTO X,16
5560 NEXT X
5570 RETURN
9000 REM
9050 REM ANY KEY HOLD ROUTINE
9100 REM
9200 OPEN #1,4,0,"K:"
9210 GET #1,C
9220 CLOSE #1
9300 RETURN
```

APPENDIX F.

Testing Patch



VITA

David Wolf was born on June 21, 1962 in Philadelphia, PA. He attended the Abington Friends High School where his interest in photography was kindled. He was given the responsibility of the school darkroom and was appointed the instructor of the Photography-minor course. Also during his high school years, Mr. Wolf operated a small business of custom black and white photographic processing and passport photos. In addition to his photographic accomplishments, he joined the Boy Scouts of America and acheived the highest rank of Eagle Scout along with becoming an Assistant Scoutmaster of his troup.

Mr. Wolf entered the Rochester Institute of Technology during the fall of 1980 in the department of Photographic Science and Instrumentation. During his freshman year at RIT, he joined the Theta Xi Fraternity which led to such positions as Scholarship Chairman, Constitution Chairman, and Treasurer. In the spring of 1983, Mr. Wolf started a computer business with a fellow student and currently manages their first store called Vixia Computer Center located in Rochester, New York.